Arctic Climate Observations Using Underwater Sound (ACOUS)

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LONG-TERM GOAL

The long-term goal of ACOUS is to advance the understanding of short (seasonal) and long-term (annual, interannual and decadal) variability in the Arctic Ocean and its relation to global climate trends.

OBJECTIVES

The principal objectives of ACOUS are (1), to establish a long term real time Arctic Ocean observing system utilizing shore cabled moorings integrating point measurements with acoustic remote sensing measurements and (2), to conduct a research program to monitor changes in the ocean temperature and thickness of ice cover in the Arctic Ocean using underwater acoustic remote sensing.

- The first objective of this research is to measure directly Arctic Ocean temperature trends and the upper mixed layer depth using acoustic thermometry and innovative acoustic technologies.
- The second objective of this research is to measure directly changes in the Arctic Ocean ice cover thickness and extent using an acoustic intensity based tomographic method.
- The third objective of this research is to assimilate the acoustic and in-situ mooring data into Arctic Ocean-Ice-Atmosphere models, and to merge them with satellite temperature, altimeter, and SAR data acquired in other programs.
- The fourth objective is to continue the close association with the Russian former defense S&T community and assist in the survival of Russian technology infrastructure and its conversion to non-defense applications. ACOUS is an approved Gore-Chernomyrdin project since 1995.

APPROACH

Install cabled and autonomous moorings equipped with acoustic sources and receivers and other oceanographic and biogeochemical sensors in the Arctic Ocean and perform long-term monitoring of Arctic Ocean temperature trends and ice cover thickness. Assimilate the data from long-term monitoring into Arctic Ocean-Ice-Atmosphere models to improve their capability and supporting data bases for more accurate forecasts of Arctic environmental changes, which are of major impact on global change and climate prediction. Use acoustic remote sensing to advance the understanding of short and long-term variability in the Arctic Ocean. Provide the basis for inter disciplinary measurements and observations for year round real time monitoring in the Arctic Ocean for a broad spectrum of the Arctic research community and ultimately transition this capability for an operational Arctic Ocean Observing System.

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Dr. Peter Mikhalevsky, SAIC, is the Principal Investigator and Chief Scientist for the ACOUS Project. Prof. Arthur Baggeroer, Massachusetts Institute of Technology, is a principal investigator on signal processing and data analysis for the Project. Dr. Mark Johnson, University of Alaska Fairbanks, is a principal investigator on Arctic Ocean-Ice-Atmosphere model development for the Project. Dr. Glenn Sheehan, Barrow Arctic Science Consortium, is a principal investigator for the ACOUS Shore Facility in Barrow, Alaska.

WORK COMPLETED

The ACOUS project installed the first acoustic source in the Arctic Ocean on October 9, 1998, at 81°55.88'N and 38°43.94'E near the shelf break at the edge of the Franz Victoria Strait between Franz Josef Land and the Svalbard Archipelago. The source transmits 10 MLS 255-digit sequences at a center frequency of 20.49 Hz, 10 cycles per digit, yielding a total signal duration of approximately 20.74 min. Each transmission starts at 0000 GMT every four days. The first regular transmission was at 0000 GMT on October 15, 1998. The source is battery-powered and designed for a life of 2.5-3 years. It is moored from the bottom with the source at a depth of 60 m below the surface. An autonomous acoustic receiving array was installed in the Lincoln Sea on October 1, 1998, at 84°03.4'N and 66°25'W, in 545-m water depth. There are eight hydrophones spaced at 70-m intervals starting at 12 m from the bottom. There are five micro CTDs that record temperature and salinity every 10 min at 14, 326, 434, 467, and 507.4 m from the bottom. The array records the acoustic data from 18 Hz to 22 Hz for 2 hours every four days, synchronized with the source transmissions. Operation of the source was verified in December 1998 by an U.S. submarine on a routine Arctic Ocean deployment.

The ACOUS team installed and operated a vertical line acoustic receive array at the SCICEX-99 APLIS Ice Camp in the Chukchi Sea in April 1999. Three scheduled transmissions of the ACOUS source were observed and two of the transmissions were recorded. The acoustic receive array used at the APLIS Ice Camp was 525 m long and contained 8 hydrophones spaced at 75 m apart, with the top hydrophone at a depth of 150 m. Three transceivers were suspended just below the ice symmetrically around the array at a distance of about 500 m. Three transponders were mounted on the array at the top, middle and bottom to provide array element location reconstruction. Signals from the regular transmissions of the source of April 9 and April 13 were received and analyzed. Analysis of single channel data shows that the source is transmitting exactly according to the specifications. The arrival times of modes 1, 2 and 3 are clear and sharp. The attached figure shows modes 2 and 3 (mode 1 is not shown as it arrives later at a time of 1880 seconds). The travel times of modes 2 and 3 were compared to the travel times measured during the TAP experiment in April 1994 and show a decrease of 2.5 seconds and 2.1 seconds respectively. A preliminary inversion of this result implies that over the 5 year period from 1994 to 1999, the Atlantic Layer of the Arctic Ocean has warmed by an additional 0.5° C.

Dr. Mikhalevsky served as the Chief Scientist of the APLIS Ice Camp. In this capacity he insured that all Ice Camp based science programs were completed, and properly coordinated with submarine operations. He also provided visiting dignitaries and press with briefings on the science being conducted at the camp.

An ATOC receive system installed at a Russian acoustic station in Kamchatka in the fall of 1996 was operated in 1998 and 1999. Data was acquired from this station from the ATOC/North Pacific Acoustic Laboratory (NPAL) acoustic source located off Kauai to expand the proposed coverage of the

NPAL. Two separate data recording periods from the acoustic station were obtained. APL/UW provided a GPS upgrade for the receive system in August 1999, and a Russian team installed the upgrade on the equipment at the station.

Three publications and two technical reports were completed, and six papers (four invited) were presented.

The following presentations were made:

P. N. Mikhalevsky, "ACOUS in Barrow, Alaska," invited paper Barrow Workshop, Arctic Research Consortium of the United States, San Francisco, CA, December 1998.

P.N. Mikhalevsky, "Arctic Climate Observations using Underwater Sound (ACOUS)," invited paper in Proceedings International Symposium Acoustic Tomography and Acoustic Thermometry, pgs 125-131, Tokyo and Yokosuka, Japan, 8-10 February 1999.

P.N. Mikhalevsky, "Arctic Climate Observations using Underwater Sound (ACOUS)," invited paper 1st Workshop On Inverse Problems On Underwater Acoustics, Heraklion, Crete, Greece, May 1999.

P.N. Mikhalevsky, "Arctic Climate Observations using Underwater Sound (ACOUS)," invited paper IUGG 99 Conference, Birmingham, England, July 1999.

P.N. Mikhalevsky, and A.N. Gavrilov, "Year Round Acoustic Observations of Temperature Variations in the Arctic Ocean," Proceedings OCEANOBS 99, International Conference on The Ocean Observing System for Climate, Saint-Raphael, France, October 13-22, 1999.

C. Bold, C.-S. Chiu, J. Colosi, B. Cornuelle, B. Dushaw, M. Dziechiuch, A. Forbes, F. Gaillard, J. Gould, B. Howe, M. Lawrence, J. Lynch, D. Menemenlis, J. Mercer, P. Mikhalevsky, W. Munk, I. Nakano, F. Schott, U. Send, R. Spindel, T. Terre, P. Worcester, C. Wunsch, "Observing the Ocean in the 2000's: A Strategy for the Role of Acoustic Tomography in Ocean Climate Observation," invited paper in Proceedings OCEANOBS 99, International Conference on The Ocean Observing System for Climate, Saint-Raphael, France, October 13-22, 1999.

The following technical reports were completed:

Bogolyubov, B.N., "Laboratory Testing of an Arctic Acoustic Souirce complex Prototype," Stage 2, Preliminary Technical Report, Nizhny Novgorod, Russia, 1998.

Bogolyubov, B.N., et al., "Designing, Manufacturing and Testing the Arctic Acoustic Source Complex Prototype," Stage 3, Final Technical Report, Institute of Applied Physics Russian Academy of Science, Advanced Science & Technology Centre "GRAN", 1999.

RESULTS

- Preliminary analysis of the ACOUS data acquired during APLIS 1999 show that the Arctic Ocean Atlantic Layer continues to warm and has warmed by an additional 0.5° C since 1994.

- Comparison of the "APLIS acoustic section" with SCICEX CTD sections from 1995, 1996, 1997, 1998, and 1999 are consistent, validating the acoustic method.
- Additional modeling and analysis of the Arctic Oscillation (AO) reported in publications this year by the ACOUS UAF researchers have lead to wide acceptance of this theory since their first identification of the phenomena in 1997.
- Analysis of the ATOC signals transmitted from Kauai and received in Kamchatka revealed several stable arrivals suitable for long-term tracking. 15 months of data have been acquired and processed.

IMPACT/APPLICATION

The ACOUS Project will provide data to enhance Arctic Ocean circulation models to improve the capability to forecast significant global environmental events. The improvement of under ice acoustic propagation modeling, development of new low-frequency acoustic source technology, and the access to Russian Arctic data bases under data sharing protocols already approved, have important payoffs. High level positive visibility in assisting Russian defense R&D to transition to non-defense applications, is another important payoff.

The ACOUS project is beginning to gather significant community support as an important method for collecting year round data on ocean temperature and ice in the high latitudes, under ice, where traditional methods are much more difficult. This conclusion will be part of the OCEANOBS 99 Final Report and Recommendations to be issued in Nov/Dec 1999. OCEANOBS 99 was an international conference on the Ocean Observing System for Climate, and included over 300 researchers, scientists, government and inter-governmental officials. The need for an ocean observatory, autonomous and acoustic thermometry cabled moorings has also been endorsed by the Barrow Area Research Support (BARS) Workshop which was sponsored by the Arctic Research Consortium of the United States (ARCUS) and NSF in 1998.

The ACOUS work and its implications for climate change in the Arctic have also captured the attention of the public. ACOUS PIs were on two radio shows this year, "Arctic Science Journeys" in January 1999 on Alaska Public Radio, and in April 1999 on WBRW, Barrow, Alaska, after the APLIS experiment discussing ACOUS and how the work relates to Barrow community issues.

There have also been numerous newspaper and magazine articles written including in the local Barrow newspaper *The Arctic Sounder*; an article entitled "The Vanishing Ice, Scientists, Submarine Probe Polar Warming," in *We Alaskans – the Anchorage Daily News Magazine*, May 1999; "Sounding Out the Ocean's Secrets" in *Beyond Discovery: The Path From Research to Human Benefit* published by the National Academy of Sciences, March 1999; "Ice Station Pieces Together Arctic's Global Sway," by Peter Spotts, *Christian Science Monitor*, May 20, 1999; "Under the Sea – at the Top of the World" in *Sea Power Magazine*, July 1999 and there will be an article in the upcoming March 2000 issue of National Geographic Magazine.

RELATED PROJECTS

1 – The North Pacific Acoustic Laboratory (NPAL) is acquiring data from the ATOC receive system installed at a Russian acoustic station in Kamchatka. The ATOC receive system was activated with support from the ACOUS Project.

2 - The SCICEX (Scientific Ice Expeditions) Project of US submarine Arctic cruises has obtained measurements along the propagation tracks that are being used by the ACOUS Project. The SCICEX data has allowed the assessment of hypothesized circulation changes, and will provide ground-truth for accurate modeling and understanding of the first acoustic measurements, as well as, an independent observation of changes that could be compared with the acoustic results.

PUBLICATIONS

Johnson, M.A., A.Y. Proshutinsky, and I. Polyakov, "Atmospheric Patterns Forcing Two Regimes of Arctic Ice-Ocean Circulation: A Return to Anticyclonic Conditions?," Geophys. Res. Lett. June1999.

Mikhalevsky, P.N., A. Gavrilov, and A.B. Baggeroer, "The Transarctic Acoustic Propagation Experiment and Climate Modeling in the Arctic," IEEE, J. Oceanic Engineering, Vol. 24, No. 2, April 1999.

Polyakov, I.V., A.Y. Proshutindky, and m. Johnson, "The Seasonal Cycle in Two Regimes of Arctic Climate," J. Geophys. Res. (In Press), 1999.